PROGRESS TOWARD TRACKING MIGRATING RAPTORS BY SATELLITE

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ABSTRACT. The ultimate objective of this radiotracking research is to track and monitor migrating birds by satellite. It is envisioned as only a part of a much broader program of satellite biological and ecological data collection (Wolff, Cote, and Painter 1975). The future need and demand for satellite tracking and monitoring of birds will very likely be focused on waterfowl and ocean birds, but large raptors, such as the Bald Eagle (*Haliaeetus leucocephalus*) and Golden Eagle (*Aquila chrysaetos*), provide ideal subjects for initial experiments. Current efforts are directed toward conducting successful feasibility experiments with these birds. Some specific objectives include equipment development and testing, animal-instrument interphase or attachment methods, evaluation of various feasibility tracking experiments with raptors, and suggestions for expediting a future program.

History of Satellite Animal Tracking

The first organized attempt to consider the feasibility and to examine the potential of satellites for tracking and monitoring wild animals was a conference sponsored jointly by the Smithsonian Institution, the American Institute of Biological Sciences (AIBS), and the National Aeronautics and Space Administration (NASA) in May 1966. In 1969 the National Academy of Sciences assembled a panel of scientists to look anew at the foundation of space biology. Wildlife behavior and ecological relationships were part of the agenda. Recommendations were made for a program for satellite tracking of free-ranging animals. One result of this meeting was a cooperative program in which an elk (*Cervus canadensis*) was tracked and monitored by the Nimbus-3 satellite (Craighead, Craighead, Cote, and Buechner 1972). This feasibility experiment was quickly followed by another to monitor a black bear's (*Ursus americanus*) winter den (Craighead, Craighead, and Varney 1971).

Subsequently, various meetings led to workshops on wildlife monitoring by satellite. A NASA/AIBS Santa Clara conference on wildlife monitoring was held 24-27 April 1973 at the Ames Research Center, Moffett Field, California. It was followed by a Santa Cruz workshop in September 1973. The purpose of these meetings and the subsequent report was "to show the importance of our wildlife resources and to show that their management, conservation and rational use are national goals, based on laws, treaties, and agreements binding between the United States and other countries as well as upon agencies of the State and Federal levels" (1973 Santa Cruz Report).

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The report stresses that state and federal agencies have established programs for which information is needed on habitat, censusing, movement, location, physiology, and behavior of animals and their populations.

Further impetus was given to animal satellite tracking and monitoring by the Easton, Maryland, workshop on Satellite Data Collection User Requirements held 18-20 May 1975.

The biology panel recommended (1) that NASA offer the community its services for liaison and information dissemination; (2) that a common data processing and standardization effort be established; (3) that NASA institute a program to develop and standardize in situ sensors; (4) that NASA support the development of recoverable packages; and (5) that NASA consider the Santa Cruz report on wildlife movement and tracking systems (Wolff et al. 1975).

Equipment Development and Testing

The 1973 Santa Cruz Report treated the application of technology to various satellite tracking programs. Two systems, RAMS and Omega/OPLE, were selected by consensus as having the greatest capability and best specifications for locating and monitoring animals and their environments. The needs of users were analyzed in terms of the required degree of equipment (transmitter) miniaturization, type of packaging, and harness required. The aim was a package needing little or no modification when fastened to the smallest (feasible) as well as the largest animal to be studied.

Attachment difficulties, which vary from species to species, can be sharply reduced by microminiaturization of the gear attached to the animal. The smaller the gear, the greater the number of species to which it can be effectively applied. Microminiaturization was based on two typical sizes of birds: large waterfowl (ducks, geese, swans), large raptors (birds of prey), and small passerines. The transmitter power, life, size, and weight are critical factors. Typical weight allowances are:

Waterfowl and Raptors	*Passerines*
100–200 g	10 g

It is estimated that electronics units manufactured under normal assembly techniques would weigh in the 200-g class. Miniaturization could achieve 80 g in a 28-cc volume in the immediate future without major effort. A subsequent step in microminiaturization can be expected to reduce this to 12 g in about 2 cc. Estimates of battery and antenna weights to be added to the above run from 40 to 1,000 g depending upon communication requirements. The total weight range is now 52 to 1,200 g. The development of the Nimbus-F/RAMS DCP one-watt transmitter weighing 56 g and compatible with Nimbus satellite frequencies (401 MHz) has been an ef fort to expedite the program and to follow the recommendations of the Santa Cruz report.

It was developed for the investigator and is being tested (Varney and Pope 1974). The work was sponsored jointly by the National Geographic Society and NASA's Ames Research Center through contracts with the Environmental Research Institute. This random access measurement system uses the Doppler location technique (G. Balmino et al. 1968). The random system transmits at predetermined intervals as compared with an ordered system, such as IRLS which responds to an interrogation from the satellite. It permits large-scale experiments at low cost using simple data collection equipment. The platforms transmit a one-second message to the satellite at random times at the rate of once per minute. The satellite records a Doppler frequency measurement and a time lag and formats the received data. This information is stored aboard the satellite for readout over the Fairbanks, Alaska, ground station and transmission to Goddard [Goddard Space Flight Center, Greenbelt, Md.] for processing. At Goddard the position location coordinates of each platform are computed, and the data is transmitted to the investigators.

The smallest available battery pack capable of operating the RAMS—compatible transmitter weighs 33 g. Operating life of the 33-g lithium battery pack would be 3.2 months or about 2.5 days/g. As mentioned, the weight of the demonstration transmitter is 56 g. The package thus weighs in the neighborhood of 100 g (56 + 33 + 10). It could be carried by a Golden Eagle, but further weight reduction is desirable for most objectives and is necessary for a comprehensive program of bird tracking. It appears that it can be reduced to about 60 g: transmitter to 20 g, battery pack to 33 g, antenna and harness to 5 plus g. This would be well within the weight-carrying capability of many migratory birds.

Briefly, the systems operate in the following fashion. Each instrumented bird carries a transmitter that transmits a constant frequency. The signals received by the Doppler equipment aboard the satellite contain the Doppler frequency shift caused by the motion of the satellite. The received frequency at the satellite varies as the satellite passes near the instrumented animal. The shape of the signal received at the satellite, combined with the known orbit of the satellite, defines two lines on the surface of the earth that run parallel to the track or orbit of the satellite. The instrumented animal is located on one of these two lines. The time at which the signal received at the satellite changes most rapidly occurs when the satellite is close to the transmitter. At this time, a plane normal to the orbit of the satellite is defined. The intersection of this plane and the surface of the earth produces a line which bisects the orbit lines and on which the transmitter or electronic animal package is located. The instrumented animal (bird) must be at one of these two intersections. These intersections are normally several hundred miles apart on the surface of the earth. Knowledge of the previous position of the animal can be used to eliminate one of the intersections (G. Balmino et al. 1968). Two fixes on locations can be made every 24 hours.

The RAMS system aboard the Nimbus-5 satellite can accommodate up to 1000 platforms per orbit. The received data is stored aboard the satellite for readout every 108 minutes (orbital period). Eight data acquisition channels allow for simultaneous reception of up to eight transmissions (Cote, DuBose, and Coates 1973).

Animal Instrument Interphase

The Santa Cruz report emphasizes that "the attachment of an electronic package to an animal is basic to acquiring position/location and other pertinent information. Any foreign object attached to an animal must be done with care so as not to introduce a physiologically or behaviorally unacceptable variant as such aberrations will degrade the value of any data acquired."

In order to test and evaluate various transmitter attachment methods, a combination 148 MHz and 462 MHz bird telemetry system was acquired and put into operation. Basically, it consisted of a 148 MHz system (Beaty 1972) with a UHF to VHF converter on the UHF antenna. The miniaturized transmitters weighed 2.8 g.

Four approaches to instrumenting or harnessing were tried: transmitter attachment to the tarsus (tarsometatarsus), attachment to the rectrices or tail feathers, the backpack harness (Dunstan 1972), and the backsack attachment. Each of the four methods has advantages for some species of birds, and one may be favored over the other depending on objectives.

Tail-feather Attachment. The tail-feather attachment falls off when the bird molts—both an advantage and a liability. Its operational life is limited to periods between molts, and its use is not feasible just prior to molting. Sooner or later the transmitter is dropped, and the bird is free of any encumbrance—a decided asset.

For the tail attachment a 4.3 g lithium battery (2.80 volts) was glued to the 2.8 g miniature transmitter using fast drying epoxy. Two strands of heavy dental floss (720 inches to the spool) were tied around the transmitter and knotted so as to leave eight loose ends or four ties. These were used to secure the transmitter to the two inner tail feathers. Two square knots were tied around the shaft of each feather—one above the other. The transmitter rested against the ventral surfaces of the feather shafts, and the knots were tied on the dorsal side. Prior to being placed on a bird, the transmitter dental floss wrapping and battery were covered with several coats of epoxy. While the more permanent tail attachment was being secured, either the bird was hooded or its head and eyes were covered with a stocking. This had a calming effect and minimized struggling. In some cases the task was made easier by lightly binding the bird's wings to its sides using several wrappings of cheesecloth or towel. With the bird immobilized, the transmitter was quickly tied to the two central tail feathers about 4 cm below the point of feather insertion. Each tie on both the ventral and dorsal side of the feather was epoxied—a precaution found necessary to prevent slippage. The antenna was tied to the shaft of one tail feather about 5 cm from the end of the feather. This knot also was coated with epoxy to prevent breaking or untying when picked at by the bird. The antenna length was as near ¼ wavelength as feasible but varied with the subject. Shortening the antenna length reduced operating range in proportion to the reduction. The antenna extended between 2.5 and 12.5 cm beyond the end of the tail. The whip antennas varied from 24 to 30 cm in length.

Tarsal Attachment. The tarsal attachment was prepared by cutting an unoiled pattern of leather to fit the species of bird to be instrumented. The transmitter with attached battery was epoxied to the leather. Two snaps permitted rapid attachment or removal. When the transmitter was to be kept on the bird for an extended period of time, a drop of epoxy was placed on each snap. The tarsal transmitter assembly was readily snapped on the subject's leg while the bird was sitting on the gloved hand. Hooding the hawks simplified the task.

Backpack Harness. The backpack harness as designed by Dunstan (1972), a modification of earlier such attachments, was used on Ravens (*Corvus corax*) and Golden Eagles. The transmitter, power source, and transmitting antenna were either embedded in perm dental acrylic (Hygienic Dental Mfg. Co., Akron, Ohio) or sealed in layers of epoxy to waterproof them and to prevent breakage. Neck and body straps of tubular teflon were used to form the harness. The present weight of a satellite transmitter package is in the neighborhood of 100 g. It seemed logical that weights ranging between 100-200 g could best be carried by a bird when attached to the back. The maximum package weight used on a Raven was 45 g. A wild Golden Eagle successfully carried a 180-g modified package while nesting.

Backsack Harness. Radio packages prepared as backpacks were sewn within a "backsack" made of ATV-16 Fabric (Cooley, Inc., Pawtucket, Rhode Island) or Saflag fabric (Safety Flag Co. of America, Pawtucket, Rhode Island). The backsack reduces the possibility of transmitter antenna breakage and also serves as a color marker during and after batter failure. A 59-cm neck strap and a 64-cm body strap made of 1-or 1.4-cm wide tubular teflon (ribbon style 8476, Bally Ribbon Mills, Bally, Pennsylvania) were centered and embedded into the ventral surface of the package. The straps formed a harness for use on either Bald Eagles or Golden Eagles.

The back package was placed on the material for the sack and sewn in place along the sack edges and across the harness straps with heavy dacron thread. The transmitter antenna was sewn in place (evenly spaced if more than one transmitter was used) between the material. A nylon tape no. 7407 Mil-T-5038E, Type III (Bally Ribbon Mills), was sewn along the edge of the backsack to minimize fraying and separation.

When placed on the eagle, the two ends of the neck staps were passed around the body in front of the wings, and the ends of the body straps were passed around in back of the wings. The four ends were joined at the midline of the breast. Straps and harness fit were adjusted to allow for growth of nestlings and molt and body size changes in full-grown eagles. Straps were joined with various suture material for short-term use and with pop rivets for long-term use.

The total length of the backsack was 41 cm, and the width of the portion covering the antenna(s) was 5.3 cm. The total length of the backsack varies with the length of the transmitting antenna, which is related to the transmission frequency. The 222 MHz transmitters used in this study had 30.4-cm antennas. The size of the anterior portion of the sack covering the power source varied in width from 9.5 to 10.5 cm depending on the size of the batteries used.

The weight of the backsack was related to the type of batteries used and ranged from 60 to 180 g. The theoretical transmitter lifetimes for this study were from 14 to 33 months. Some actual lifetimes are still to be determined as the work on some birds continues.

The use of solar cells to recharge transmitter batteries has been increasing and is being perfected. Solar panels kept the batteries recharged on the IRLS equipment used to track an elk (Craighead et al. 1972). They have been used successfully on turkeys (*Meleagris gallopavo*) and mule deer (*Odocoileus hemionus*) (Patton, Beaty, and Smith 1971). The antenna sheath used to prevent antenna breakage by Golden Eagles (Dunstan 1976) could readily be used to house solar cells for recharging of satellite-transmitter batteries thus assuring longer life at reduced weights.

Radio transmitter backsacks were placed on two adult female Golden Eagles, four nestling Golden Eagles, and four nestling Bald Eagles. All birds carried the backsacks well, and neither the young nor the adults showed concern for the presence of the backsack. The marked adult female Golden Eagles continued to kill prey and feed young after tagging. Golden Eagle nestlings with backsacks were fed by unmarked adults at the same rate as prior to tagging, and the adults showed no unusual behavior in relation to tagged nestlings. The Golden Eagle nestlings fledged and dispersed from the parental ranges well within the time ranges for the same activities of other unmarked young. The tagged nestling Bald Eagles were fed regularly by the unmarked parents and also fledged and dispersed from the home ranges within the time limits for other unmarked young in the study areas. The backsacks used on the adult Golden Eagles were green and those used on the nestling Bald Eagles and Golden Eagles were yellow.

Occasionally the adults and young preened the antenna portion of the sacks and the harness straps. During these preening bouts the antennas were not sharply bent, and the force of pulling was absorbed by the entire harness. The distal portion of the sack, including the antenna, sometimes slipped from the middle of the back to either side along the flank, but most of the time the sack remained toward the middle of the bird's back. The scapular feathers often covered a portion of the proximal (anterior) portion of the sack, but the distal half of the sack was visible.

Three marked eagles (two of which were marked under BLM contract 525 CO-CT 5-1013) were later captured and appeared to show no adverse affects from the tagging. One fledgling Golden Eagle wore a backsack for 11 weeks before being recaptured. A second recaptured Golden Eagle had worn a backsack for 53 days after fledging. Neither bird showed any damage to skin, feathers, or the backsack. However, both were in poor physical condition when captured. One had a case of *Trichomonas gallinae* and had lost considerable weight. The second had lost considerable weight, apparently from lack of food, but was not diseased. One nestling Bald Eagle marked with a backsack with no transmitter on 23 July 1974 was found shot in Iowa in December 1974, 624 km from the Minnesota nest site. The feathers, skin, and backsack of this bird were undamaged when examined.

Evidence indicates that the radio transmitter backsack works well on nestling, fledgling, and adult eagles. Antenna breakage is minimized, and, after the transmitter power source fails, the backsack acts as a color marker for long-term use. More than one transmitter with separate antennas can be placed in a backsack. The use of two transmitters will become important when monitoring both location and physiological parameters, such as core temperature and EKG, becomes practical. It is also possible to place a long-range, short-term transmitter for satellite tracking in combination with a shorter-range, longer-term transmitter for location from the ground in the same backsack. This combination would facilitate global location via satellite during migration, followed by short-distance ground observations for behavioral and recap ture studies.

Of the four attachments tested, the backpack and backsack harnesses appear to be the first choices for satellite feasibility experiments using the present RAMS DCP transmitter. With the RAMS transmitter, a 33-g lithium cell would provide an operating lifetime of 3.2 months (Varney and Pope 1974). An eight-month lifetime is a reasonable goal to obtain optimum results. A 99-g lithium battery pack would provide eight months of operating time. The backsack has the drawback that it is not readily dropped when the package is no longer functioning. Using materials that disintegrate (e.g., when exposed to sunshine) should permit ultimate release. This is an area for continued research.

The tail attachment proved to be quite suitable for Ravens and raptors. However, this package weighed under 10 g—transmitter 2.8 g, battery 4.3 g, harness less than 2 g. With the maximum amount of miniaturization available from present advanced technology, the RAMS transmitter could be reduced to 20 g and could conceivably be used to track Golden and Bald Eagles using the tail feather attachment. The tail assembly was received well by all subjects. After a little initial preening, the transmitter was largely ignored and had no noticeable effects on flight performance. The tarsal attachment proved largely unsuccessful for raptors as the birds often bent, twisted, and even completely broke off the whip antennas. It was quite useful and convenient for instrumenting birds for periods of tracking lasting only a few days. It should prove more useful for waterfowl, but winter use with freezing conditions would definitely present problems.

Possible Feasibility Experiments

Although further equipment development and testing will be required, we have now reached a point where we can consider various feasibility experiments with the Nimbus Satellite using a large instrumented raptor as the subject. The approximate 100-g weight of the RAMS transmitter, battery pack, and harness are well within the weight-carrying capacity demonstrated for Golden or Bald Eagles. The current weight precludes all but the backpack attachment, but this does not appear to offer any real deterrents. Whether a Bald or Golden Eagle is selected may well depend upon the time of year when experiments can be undertaken. Timing will be dependent upon a number of factors, one of which will be successful completion of fixed-position transmitter tests. Ideally, the experiment not only should demonstrate the feasibility of satellite tracking, but also should provide information not hitherto available. Three possible experiments are described briefly below.

1. The tracking of a mature or an immature Golden or Bald Eagle of the year (fledgling) from a far northern nesting site would probably provide a distant flight over a relatively short period of time.
2. Adult eagles of either species trapped and instrumented at concentration sites should provide migratory or dispersal data, but movements might be limited as compared to fall or spring migratory flights. Examples of such possibilities include instrumenting adult Bald Eagles at winter concentrations in Alaska (Seward or Juneau) or in Washington (Skagit River). Migratory patterns of these west coast eagles are not well known and lend themselves to discovery through satellite tracking (Buechner et al. 1971). Immature Golden Eagles, such as those concentrating in spring at lambing areas in Montana, could be readily trapped and instrumented. Doing so might provide information on a raptor-prey problem of economic significance. Movement might be extensive or relatively restricted, but data could be obtained on where such birds come from and where they go when they disperse.
3. Golden eagles, either young or adult, instrumented at the Snake River Birds of Prey Natural Area (Idaho) would provide information not now available on eagle migration and movement out of this intensively studied area.

When further miniaturization of the present RAMS transmitter is accomplished, other projects will be feasible, such as plotting the migratory routes of Peregrine Falcons nesting in the far north. Nesting populations of Peregrines in Alaska are definitely on the decline; chlorinated hydrocarbon pesticides picked up in wintering areas are implicated (White and Cade 1971). Some remedial measures might be possible if wintering grounds in South America could be pinpointed by satellite tracking.

Conclusion

We have treated here only the satellite tracking of birds and have limited our presentation largely to raptors. However, migratory movements can be correlated with daily weather maps and habitat delineation and evaluation can and will accompany movement studies using satellite tracking. Stopover or resting areas of migrating birds can be evaluated at to habitat preference and type. So can nesting and wintering areas. The Lansat multi-spectral imagery or U2 photographs, when accompanied by ground truth, can also be used for this purpose (Craighead 1976). Accompanying censuses of nesting and wintering concentrations is a possibility. Such information is in great demand. Further advances in technology may be needed for censuses, but once such a goal is set, progress toward achieving it will accelerate.

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